MT Bilimsel™
Yıl:5 | Sayı:9 | Ocak 2016
Year:5 | Number:9 | January 2016
Yer Altı Kaynakları Dergisi | *Journal of Underground Resources*
www.mtbilimsel.com

Makale Gönderim Tarihi: 19.08.2015
Yayına Kabul Tarihi: 05.09.2015

Rock Bolting from Past to Present in 20 Inventions

Eren Kömürlü [1]*
Ayhan Kesimal [1]
[1] *Karadeniz Technical University, Department of Mining Engineering, Trabzon, Turkey,*
** Corresponding author: ekomurlu@ktu.edu.tr, erenkomurlu@gmail.com, tel: 0462 377 42 97*

Abstract
This work aims to better understand improvements in history of the rock bolt support. Although the rock bolt was invented more than one hundred years before, its usage has increased in mining and tunneling industries since the 1930s. Then, the steel rock bolts have become one of the most widely used tunnel supports since the third quarter of the 20th century, which was a time of changing strategies regarding supports and many challenges faced concerning the use of new support materials. Twenty inventions in the rock bolt history from its start of usage to nowadays are briefly explained in this paper. It can be inferred from the listed matters in this paper that many of the important developments in the rock bolt history were because of the need for use of new materials like contemporary grout materials increasing the load bearing capacity or rock bolts made with engineering polymer materials having good resistivity against the ground water. Also, developments in the mechanical science have made rock bolting an effective support method due to improvements such in the drilling technology or new anchoring mechanisms developed to overcome the problems in rock bolting. As a result of growing applications during 20th and 21th centuries, new challenges have come into being as in the energy-absorbing rock bolts being improved for the rock burst problem since 1990s.
Key words: Rock bolts, rock bolt history, rock support, tunnelling history, material handling in rock engineering, underground support.

1. Introduction

Although the first date for use of rock bolts is not clear, the first rock bolt patent application is known to be done in 1913 by Stephan, Fröhlich and Klüpfel who introduced their invention used in German coal mines as grouted steel rebar type of rock bolt (Stephan et al., 1918). In 1930's, the rock bolts also known to be applied in USA in early 20th century systematically started to be used in US mining industry (Gardner, 1971; Tully, 1987).

As a result of invention of the contemporary support systems, tunnel excavations have been able to be carried out with lower costs. Principally, the background of the contemporary support strategy had been made for long years. One of the most important improvements for having the opportunity to excavate underground openings with large-cross sections in weak rock zones can be accepted to be new materials use in rock support. Before the invention of use of steel materials in the rock engineering, the main support material was wood that caused many of different rock mass properties which are able to be supported in today's conditions impossible to perform engineering applications in history.

Many of the important civilisations in ancient times like Romans, Babylons, Eqyptians, Persians, Astecs, Incas excavated tunnels for different aims such as mining, transportation, drainage, hiding and living, fighting in wars. Egyptians and Romans are known to excavate mining tunnels at the depths reaching 200 meters in the ancient times. The Roman Empire was the first country to have a special ministry on water transportation (Sandstrom, 1963). Therefore, many of the Roman tunnels were excavated under the official inspections of the empire. Some of the Roman tunnels excavated in the ancient times can be still considered big engineering applications in today's conditions.

Findings for the 6th Century BC refer that people could excavate tunnels in hard rocks with the rate of 9-10 meters per a year (Fukushima, 2012). One of the three wonders of the Hellenistic world was a water transportation tunnel with 1 km length whose the excavation was completed in 530 BC. The name of tunnel considered as a wonder of Hellenistic world is Eupalinos which was excavated in the Samos Island of Greece. Then, the excavation rates and the length of tunnels increased by the Roman Empire that excavated the biggest tunnels of the ancient times. A Roman tunnel excavated for draining the water of Fucino lake in Italy was the longest tunnel until 1876. Excavation of the tunnel with 5.8 kilometers length and depth reaching 120 meters was started by the Emperor Cladius (a.d. 11-54) and completed in 11 years. For excavation of the tunnel, 30000 people worked to excavate the total length of over 10 km including the shafts (Parry, 2013). Another important Roman tunnel was excavated to divert the floodwaters threatening the harbour near the ancient city of Seleucia Pieria in Turkey nearly before 2000 years. The tunnel with the name of Titus tunnel was started to excavate by Emperor Vespasian (a.d. 9-79) and also excavated during the time of Emperor Titus (a.d. 39-81). Considering the cross-section area of tunnel excavation of over 50m2 and length of 1.4 kilometers, it can be said that the 2000 years old Titus tunnel is an important heritage from the ancient times and still an important tunnelling project in today's conditions.

It was a quite tough job to manually excavate tunnels in history. For making rock masses be excavated with an easier way, fire was made on face and quenched by pouring water for an immediate change in temperature which causes cracking. After the quenching, it was easier to excavate rock using metal tools (Wahlstrom, 1973). An example of ancient excavation marks from the Titus tunnel is given in Figure 1. Although excavation rates could be increased significantly as a result of the developments in the excavation tools due to the improvements in metallurgy, it should be noted herein that the human power was the main need to have a success in the tunnelling in the ancient times.

Figure 1. a) A view of the Titus tunnel, b) excavation tool Marks

Although the metal tools were used to excavate rock since very early times, metals were not used to support rock masses until the 18th century. In terms of economical use of metals as support material, developments in the metallurgy during the 18th century have made an important background for important inventions. Steel material being widely used as support material in todays was firstly used for an aim except making weapon, tools and some goods in 1778, as being the construction material of the Coalbrookdale Bridge in England (Baugh and Elrington, 1985). For the start of steel material use as construction material, the Abraham Darby's invention to make coke from coal was an important milestone which caused to produce steel materials with cheaper costs. English ironmaster Henry Court's invention of puddling process was also an important milestone for having high strength steel materials.

The first time to use steel support material for rock supporting was just 17 years after the first steel construction of the Coalbrookdale Bridge. In 1795, steel lining support was firstly applied to support a coal mine shaft in England. A prefabricated steel lining shaft support from 1850's that was used in another coal mine of England is shown in Figure 2. Prefabricated steel liner supports had become a widely used support, and started to be applied as tunnel lining in addition to being shaft support in 19th century. The first prefabricated steel lining tunnel support was used in a subway tunnel construction in London. Because of the development in concrete science, cheaper prefabricated concrete liners have taken the place of steel lining supports. However, steel ribs are being still used and most widely seen conventional support in tunnel constructions. By using steel support, higher strength and more practical supports with lower prices could be set in comparison with the previous support methods such as timbering and bricking. Until shotcrete material became wide in tunnelling, steel ribs were used with wood support. Steel ribs had started to be used in several European countries in the second half of the 19th century (Merivale, 1888).

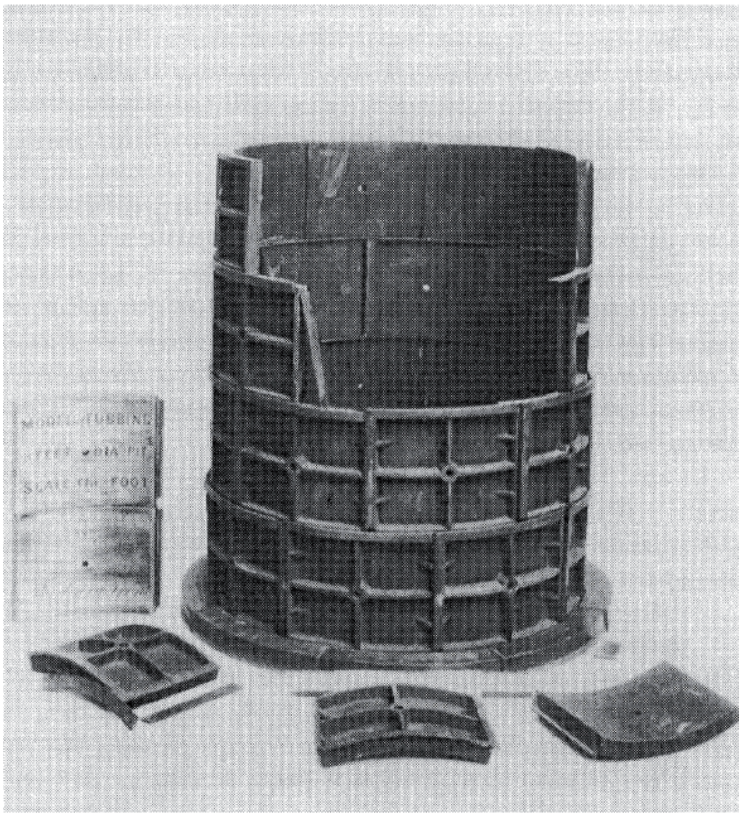

Figure 2. Steel shaft liner support produced in 1859 (West, 1988)

There were notable developments in the 19th century which established tunnelling as a modern industry. As a result of inventions of drilling machines and effective explosives with nitroglycerin, the excavation rates in tunnelling have been increased significantly in the 19th century. As drilling machines have made rock bolts possible to be applied practically, frontiers of rock excavation in the 19th century also had an important role on the development of the rock bolt supports in addition to the entrance of the steel supports into the rock engineering applications.

In the 19th century, numerous tunnel projects were needed to set network for the reason of increasing transportation requirement resulting from the industrial revolution. Different European countries developed their own tunnelling methods in 18th and 19th centuries (English method, German method, Belgian method, Austrian method, etc.). However, the most important revolution can be accepted to be in the 20th century with the new Austrian tunnelling method (NATM). The most important difference of contemporary support strategy of the NATM firstly introduced in 1950's was considering rock mass to support itself which can be supplied using rock bolts and shotcrete (Muller, 1990).

2. Twenty Milestones in History of Rock Bolting

2.1. The First Rock Bolt Patent

The first time to use rock bolts is not definite and believed to be late 19th century. Although the first patent for the rock bolt support was applied by Stephan, Fröhlich and Klüpfel in 1913, the patent in rock bolt history was got in 1918. The long delay in the time for getting patent was probably because of the 1st World War (Kovari, 2003b). Stephan et al. (1918) reported that two different locations in ground can be linked using the grouted rock bolts inserted in drill holes. Therefore, it is explicitly understood that the firstly patented rock bolt was the grouted rebar type bolt.

2.2. Some examples Making Rock Bolt Use Popular in Europe and North America

Although rock bolts could not become a widely used support in 1920's, they have fastly grown up in tunnelling since 1930's and become popular in 1960's (Kovari, 2003a). The 20th century was the century of changing support strategies and many challenges based on using new support materials. The New Austrian Tunnelling Method (NATM) named in the second half of 50's was developed as a result of using rock bolts with shotcrete in tunnel supporting (Muller, 1990). Some important examples which made rock bolting widely applied can be listed as follows:

- In 1930, rock bolts were applied in tunnels of Keyhole dam in USA
- Rock Bolts started to be used in a Canadian mine of Melntyre in 1934
- In 1942, rock bolts were firstly applied in Europe for transportation (motorway) tunnels excavated in England.
- From 1948 to 1950, rock bolts were applied in underground coal mine galleries with a total length of 1400 km in USA.
- In 1950, rock bolts were used in a water carrying tunnel excavated in Manchester.
- In 1950's, rock bolts were applied in several dam constructions in Canada, Norway, Sweden and France.

From 1958 to 1962, rock bolts were applied in a motorway tunnel with a depth reaching 2200 meters and length of 11,6 km, between France and Italy.

2.3. Portland Cement

Grout quality is one of the most important issues in rock bolt support performance. In terms of having a better grout material, invention of Portland cement which is the most widely used cement material all through the world is a significant improvement in the rock bolting practices. The Portland cement was invented by an English chemist of Joseph Aspdin in 1824 (Aspdin, 1824). As the color of the cement is close to that of limestone of the Portland island in England, it is called as Portland cement. The first Portland cement was introduced to market selling it as a modern binder material in 1845 (Eckel, 1913).

2.4. Shotcrete

In terms of the success of contemporary support strategies, use of rock bolt with shotcrete has a capital importance because of bettering the performances of each other. Shotcrete has important advantages to control deformations of the bolted ground. Before the use of shotcrete in tunnelling, iron plates were used to link bolts each other and supply support pressure on the wall which results from the load bearing by the rock bolts (Figure 3). The invention of shotcrete and its use with rock bolts were the main reasons for realising the contemporary support mentality firstly detailed with the NATM (Rabcewicz and Golser, 1973).

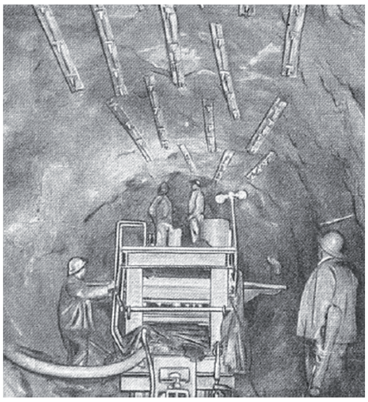

Figure 3. A rock bolt application in 1950's (Perez, 1952)

The first spraying concrete called gunite was found by an American taxidermist of Carl Akeley to be used with animal models in early years of the 20th century. In the first system, solid was being carried by air and water was being mixed immediately before spraying from the nozzle. Carl Akeley got the patent of his invention of the cement gun in 1911. The most important difference of the Akeley's method in comparison with the typical shotcrete applications is using no mixer to make the sprayed concrete. The first mixer machine was invented by Chester A. Beach in 1910, just a year before the invention of Akeley (Bicik, 2012). Therefore, it can be inferred that all the concrete materials were manually mixed in 19th century.

First shotcrete application performed in an American mine is known to be in 1914. In 1930's, American railway engineering association (AREA) firstly used the name of "shotcrete". Early shotcrete applications were performed as dry mix that water and solid were mixed in a mixer used in application area and sprayed with air pressure. Wet mix shotcrete which is mixed outside of application area and generally transported by the mixer trucks has started to apply in 1950's.

2.5. The First Frictional Rock Holts (Split Sets)

The frictional rock bolt was invented by an American Engineer, Dr. James Scott in 1972 (Scott, 1974; Davis, 1979; Scott, 1981). Because the system is quick and simple to install, it fastly gained acceptance by miners all throught the world. As it is installed by pushing into a hole with slightly lower diameter than that of the rock bolt, the radial spring force is generated by the compression of the tube with cross-section of C shape, which provides the frictional anchorage. Although increase in the normal forces applying on the drill hole surface is an advantage in terms of the frictional load bearing capacity, having a high ratio of tube diameter to drill hole diameter is a disadvantage for the insertion performance of the rock bolts. Split set type of rock bolts generally have similar load bearing capacity with the load level reached during the insertion. Although the load bearing capacity increases due to increase in the split set tube wall thickness and/or diameter, insertion practicality of the rock bolts is affected as a result of increase in the split set tube wall thickness and/or diameter. Furthermore, the corrosion problem getting worse by scratching of the steel surface contacting to the drill hole should be payed attention with the increase of tube diameter (Li and Lindbald, 1999; Hassell ve Villaescusa, 2005).

2.6. Another Frictional Rock Bolt: Swellex

Atlas Copco invented the swellex type frictional rock bolts in 1980's. Because the swellex type rock bolt tubes have smaller diameter than the drill hole diameter before insertion, it needs to be expanded in the drill holes to supply frictional load bearing capacity. One of the most important advantages of the swellex type rock bolts is having no significant scratching problem during their insertion which limits the frictional load bearing capacity as in the split sets application. Therefore, higher stress applying on the hole surface from the swellex type tubes can be supplied in comparison with those in the split set applications.

2.7. Resin Type Grouts

The first resin grout product was developed in Germany, in 1956. The resin grouts which need short time for curing reactions are usable for the rock bolts that start to carry load in short time as insertion is done. The first application carried out in 1959 to use resin grout cardridges was also in Germany. Nowadays, many different resin grout materials having a significant variety can be found in the market. Mechanical properties of resin grouts can change using chemical additives. Resistivities against the ground water and dynamic load resulting from the blasting applications are important issues making the resin grouts advantageous in comparision with the conventional cement grouts (Hoek, 2006; Komurlu and Kesimal, 2013a).

2.8. The First Mechanically Anchored Rock Bolts

The first rock bolt having expansion device at the front of the shank for the mechanical anchoring was firstly used in construction of an Australian dam called "Snowy Mountains Scheme" in 1947 (Meacham, 2007). The first application carried out in Australia was an important milestone for the invention of the modern pre-tensioned rock bolts being able to supply active support pressure without the need for the ground deformation.

2.9. Cable Bolts

Hoek et al. (1995) reported that cable bolts were firstly applied in underground mining in Canada in 1963. In 1964, cable bolts were also started to use in South African mines. Because cable bolts were able to be inserted for support of deep rock masses, they were found convenient to use in rock engineering and became a widely used support in Australian and Scandinavian mines in 1970's. During 1980's and 1990's, cable bolts became a typical mine support all through the world, support reaction of cable bolts have been well understood and different kinds of cable bolts were produced (Yazici and Kaiser, 1992; Kaiser et al., 1992; Hyett, 1992; Windsor, 1992; Hutchinson and Diedrichs, 1996).

2.10. Polymer Composite Rock Bolts

For the aim of eliminating the affect of ground water, composites of engineering polymers having no corrosion problem and proper mechanical properties were started to use in 1985. The first application of the polymeric rock bolts was carried out in Switzerland (Firep, 2013). Light density of the polymer composite rock bolts is another advantage in terms of the application practicality. Polymer composite rock bolts are generally made with glass or carbon fiber reinforcement used in the matrix of polymer materials such as ABS (Acrylonitrile Butadiene Styrene), epoxy, polyester, vinylester (Komurlu and Kesimal, 2013b). Depending on the production details and additives, it is possible to find the polymer composites being much stronger material in compasion with the steel widely used in rock support applications.

2.11. Cone Bolts

To combat rock burst problem in deep mines, many challenges have been faced concerning the use of new rock bolts. The first rock bolt developed to use in the mines having rock burst problem is the cone bolts having increased energy absorbing capacity resulting from the anchoring of cone end of the shank. The cone bolts firstly used in 1992 have a simple design with an expanded front end which can increase the anchoring performance in the grout material, were developed in South Africa (Jager, 1992).

2.12. Energy absorbing rock bolts with sliding body (Garford, Roofex)

In 2008, Garford bolt (Australia) and Roofex bolt (Sweden) were developed to increase the energy absorbing capacity against the dynamic load resulting from the rockburst problems, consisting of a solid steel bar sliding in polymeric materials, an anchor and a coarse-threaded sleeve at the far end of the bolt. The Garford and Roofex bolts have a high deformation limit, ductile support reactions and also high static load bearing capacity which make the support effective to combat rock burst problem (Li et al., 2014). As the increase of mining depths make miners face with the rock burst problem, the energy absorbing rock bolts seem to be used more widely in future than being in todays. Figure 4 illustrates the high deformation let by the Roofex type energy absorbing rock bolts.

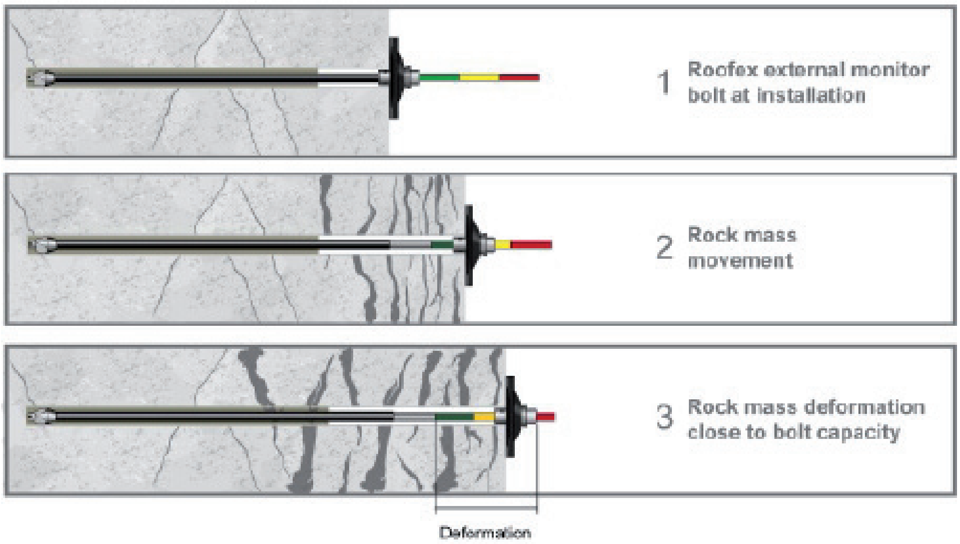

Figure 4. Deformation let by Roofex bolts (Atlas Copco, 2015)

2.13. Thin Spray-on Liner Coated Rock Bolts

The deficiencies of tunnel supporting lead up to be improved by including the use of new materials. Corrosion problem can be considered as the most important problem of steel support usage. Underground water can substantially affect steel support material and decrease the load bearing capacity especially for long terms and acidic underground water conditions (Ranasooriya et al., 1995; Li and Lindblad, 1999; Komurlu, 2012; Hassell and Villaescusa, 2005).

The polyurea-type thin spray-on liner was firstly applied to be water resisting coating for the steel rock bolts in 2013 (Komurlu et al., 2014; Komurlu and Kesimal, 2014). Polyurea is an isocyanate-based copolymer used for surface treatment applications, such as liners for truck beds, tanks, ships, buildings, pools, and waste deposition isolation plants, beacause of its good water-resisting performance (Komurlu and Kesimal, 2012). Polyurea is being used as spraying membrane in tunnelling and a support called thin spray-on liner (TSL) (Holter, 2014; Ozturk, 2012). It has good adhesion with rock, concrete and steel surfaces (Ozturk and Tannant, 2010; Tannant, 2001; Komurlu and Kesimal, 2013b; Jain and Gupta, 2012; Ozturk, 2012; Komurlu and Kesimal, 2012; BASF, 2009).

A Turkish copper mine with acidic underground water condition was the first area to apply the polyurea coated rock bolts. Rebar and split set types of rock bolts were easily coated with polymer spraying method. It was found that material and workmanship costs for the surface treatment method are quite low; two people can easily coat more than 100 rock bolts in one hour. Long and short terms pull-out tests were separately performed on polyurea coated and uncoated rock bolts to examine the effect of the surface treatment method on rock bolt corrosion and load bearing capacity. It was confirmed by the tests applied on the grouted rebars that polyurea has excellent adhesion with steel and cement mix injections. In addition, the substantial increase in pull-out test results for the split-set-type frictional bolt showed that the polyurea coating adheres well to the hole surface. The results indicated that polyurea coat significantly increases frictional load bearing performance of the contact between the bolt and the rock surface. It was observed from the field study that polyurea type TSL prevented steel corrosion economically while bolt load bearing capacity was being increased significantly (Komurlu and Kesimal, 2014). Figure 5 shows the polyurea type thin spray-on liner coating and the surface of polyurea coated rock bolts.

2.14. Frictional Rock Bolts with Plastic Body

Komurlu and Kesimal (2015) have started to investigate the use of fiber reinforced engineering polymer tubes as frictional rock bolt, obtained proper load bearing capacities with tests applied using the plastic frictional bolts. The plastic frictional bolts developed by Komurlu and Kesimal are plastic type split sets which have thicker tube wall in comparison with typical steel split sets. The fitting devices, material handling and application details for the plastic split-sets are still being developed with laboratory and field studies performed in Turkey and Australia. Some field studies showed that frictional load bearing capacities of steel split sets applied in a mine with acidic underground water problems resulting from sulphuric ore content can decrease by 400% only within several months, although they are galvanized (Komurlu and Kesimal, 2015). New, economical and high strength polymeric split sets with high chemical resistivity are expected to be helpful for improving the rock bolt performance especially for the corrosive ground conditions.

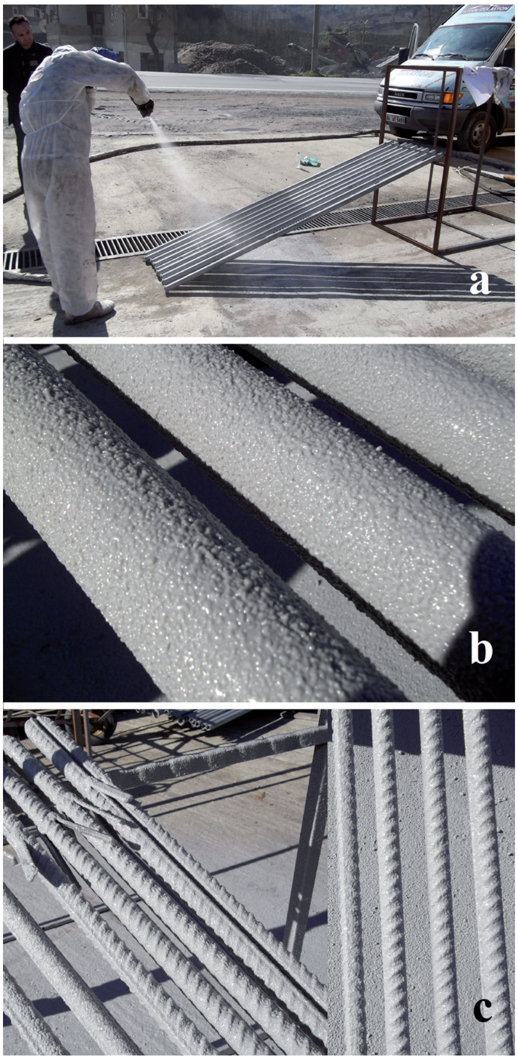

Figure 5. Polyurea coating on rock bolts, a) spray-application of polyurea coating, b) polyurea coated split set bolts, c) polyurea coated rebar bolts (Komurlu and Kesimal, 2014)

2.15. Tungsten carbide drill bits

The improvements in the drilling technology were not only increasing the rate of excavation, but also made rock bolt application easier and more effective. The invention of drill bits with tungsten carbide tips can be accepted to be one of the most important inventions of drilling in rock engineering.

The invention of the electric furnace in 19th century opened the way for experiments on the reactions of elements at very high temperatures which could make tungsten carbide possible to be produced. The tungsten carbide alloy firstly produced in the late 19th century was an important milostone in rock engineering which was firstly produced in France. In 1920's, a German firm took over the production of sintered tungsten carbide products and introduced hard metal alloys made from sintered tungsten carbide which were marketed under the name "Widia" meaning "like diamond". In 1928, the manufacture of sintered tungsten carbide tools began to be sold in outside of Germany. The production of sintered tungsten carbide in Germany rose from 1 ton per month in 1930 to 40 tons per month in 1944 (West, 1988).

Indeed, results of the idea of using rock drill bits with early tungsten carbide tips were not desired because of brittleness and brazing difficulties. The idea was taken up in the early 1940s as a result of co-operation between Atlas Diesel (Atlas Copco in todays) and Luma which was a firm making electric light bulbs. Atlas designed the sintered tungsten carbide bits and Luma manufactured them. Later on, Luma's tungsten carbide manufacturing operation was taken over by the Sandvik, but Atlas and Sandvik continued with the joint development work. In 1947, many of the difficulties to produce economical and effective drill bits with tungsten carbide tips had been overcome and the world-famous drill steels tipped with sintered tungsten carbide came onto the market (Gardlund et al., 1974).

2.16. Compressed Air Rock Drilling Machines

Before the 1850s, the method of driving tunnels was same with that used for the previous 200 years. The heading was advanced by drilling a number of holes into the face. The drilling was done by a man holding the drill steel and two other men hammering to penetrate the drilling steel into the face. The basic features of the method are illustrated in Figure 6. A drilling steel would only drill about 0.3 m because of becoming blunt. A procession of men, or boys, carried sharp drill steels to the face and took the blunt drilling steels to bring them for resharpening. Drilling rates for a single hole were as slow as a meter per three hours (Stauffer, 1906). After having the enough number of holes drilled into the face, the holes were charged with gunpowder also called "black powder".

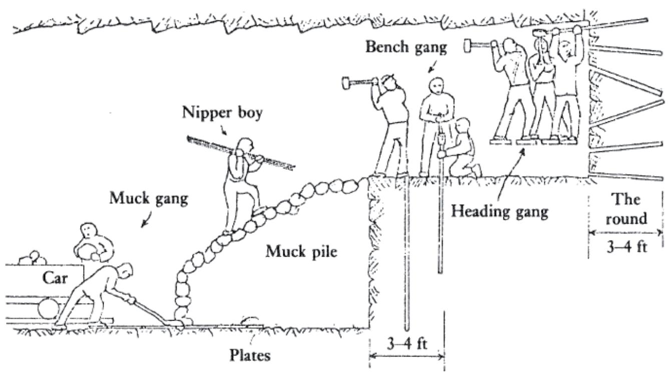

Figure 6. Tunnel driving in first half of the 19th Century (West, 1988)

From the 1850s, tunnelling was revolutionised by extremely important innovations such as the compressed air rock drilling machine use in 1850s, the use of nitroglycerine explosive in 1860s, the tungsten carbide drill bit in 1940s, the hydraulic rock drilling machine in 1970s.

Although the steam engine was available as a source of power for operating a rock drill in 1840s and 1850s, a steam boiler could not be operated in the space of a tunnel as the exhausting steam was a big disadvantage making the working atmosphere intolerable. A solution to the problem was using compressed air rock drilling machines for driving holes into the face. Air compressed drilling machines was used in 1850s in European mining industry. The first time for use of air compressed drilling machines in tunnelling industry is known to be 1861. The Mont Cenis Tunnel was built to provide a railway connection between Chambery in France and Turin in Italy. Construction started in 1857 and the tunnel was constructed by manual drilling until 1861, with the advance rate of only 7 meters per month. Germano Sommeiller was responsible for the design of the rock drilling machines to increase the efficiency in the tunnel excavation. He introduced air drilling machine to be used in the Mont Cenis Tunnel in 1861 (West, 1988). As mechanised rock drilling in the Mont Cenis Tunnel had become to be a routine operation by the middle 1860s, the rate of advance increased to 70 meters per month.

The first use of compressed air rock drilling machine in USA tunnels was at the Hoosac tunnel in 1866. During the 1860s, different rock drilling machines were being fastly developed in United States of America, an engineer, Charles Burleigh worked on and produced an efficient compressed air rock drilling machines to be used in tunnelling industry. The Burleigh drill machine was started to use in Hoosac tunnel and significant improvements in the machine was carried out with new works (Andre, 1876). A sketch of the Burleigh's compressed air drilling machine produced in 1870 is shown in Figure 7.

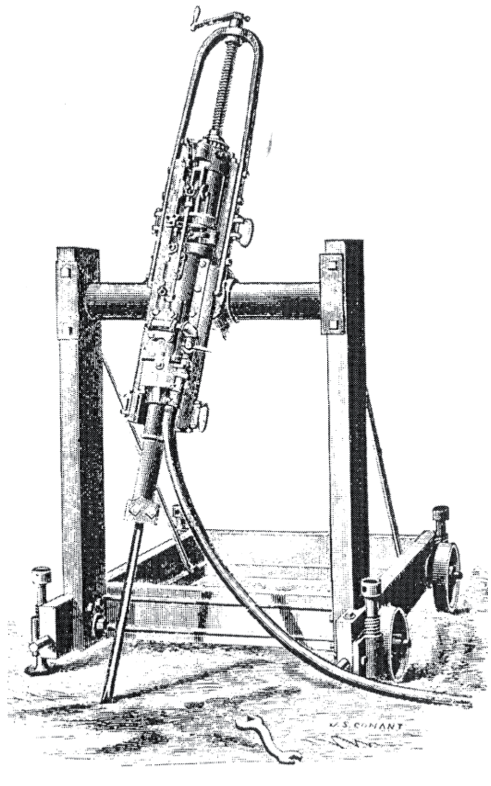

Figure 7. A primitive rock drilling machine, Burleigh's drill used in 19th century (Andre, 1876)

2.17. Hydraulic Drillers

In 1876, the first hydraulic rock drilling machine was invented by a German engineer, Alfred Brandt (1846-98). Brandt had the idea of utilising the water power directly for avoiding the energy loss involved in compressed air method. He firstly developed a percussive type rock drill machine similar to the compressed air rock drills except that it was driven by water pressure instead of compressed air. Although the first machine was unsuccessful, it was important milestone for the second drilling machine of Brandt which was successfully used in rock drilling applications (Sandstrom, 1963). The second machine was operated with the water consumption of 1.8-2.5 m3 per hour. Its hydraulic engine developed 8-15 hp and run at 200-300 revolutions per minute. (Stauffer, 1906) By the development in hydraulic rock drilling machines, oil was started to use instead of water, and modern drilling machines used in nowadays have been shaped.

2.18. Jumbo Driller Machine

Because heavy driller machines and devices being able to drill holes with high lengths has to be hold and controlled effectively, proper mounting equipments were needed to use. Invention of the jumbo drillers can be accepted to be an important stage in development of modern drilling machines. The first working hydraulic percussive rock drills with hydraulically-controlled articulated arms were pioneered by Montabert which is a major drilling equipment manufacturer situated in France. The first machine was introduced in 1969. Then, the jumbo machines were fastly developed in different countries. Six European and two American drill machine manufacturers had their own versions of the new hydraulic rotary percussive rock drilling machine in 1974 (West, 1988).

Jumbo driller has made easy to drill holes in rock engineering and significantly increased the excavation rates. As well as excavation, modern jumbo drillers have significantly bettered the practicality of the rock bolting applications. Before the invention of jumbo driller machine, it was not practical to drill rock bolt holes especially for the roof. The increase of drilling efficiency due to the developments in machinery science is illustrated in Figure 8.

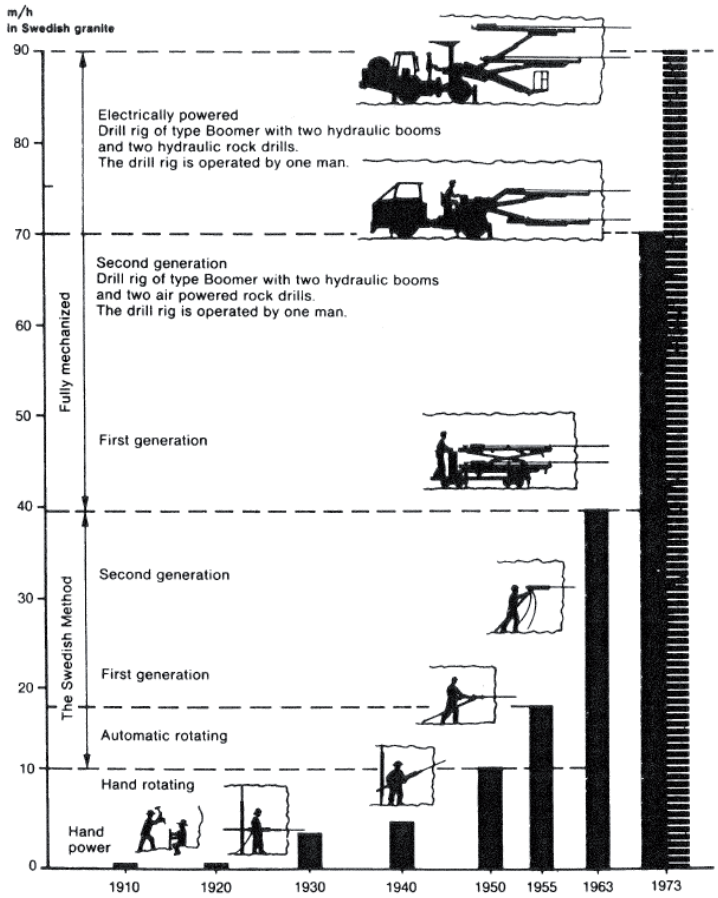

Figure 8. Increase in drilling rates (West, 1988)

2.19. Rock Bolter Machines
Jumbo drillers have been modified to be able to insert rock bolts in addition to drilling the holes rock bolts are inserted in. The machines called as rock bolter also have devices to grout the hole. Therefore, they have made rock bolt application more practical and significantly decreased the time needed for carrying out the rock bolt applications. The rock bolters are known to use in 1980s (Nelson, 1986)

2.20. Self-drilling Bolts
The self-drilling bolts used since 1980's have front part with drill-bit and enable high rates of installation, good directional stability and also help to consolidate the grout within the borehole. Self-drilling rock bolts provide a unique bolting solution for unstable drill-hole conditions as in drilling in highly fractured rock masses. The technique of the self-drilling can be accepted to supply an important contribution to the rock bolting. Figure9 shows a self-drilling type rock bolt.

Figure 9. Self-drilling rock bolt (URL1)

3. Conclusions
The invention of the rock bolts can be accepted to base on the improvements of material and engineering sciences in 18th and 19th centuries. Because of increasing demand for new transportation networks which mostly resulted from the industrial revolution and finding opportunity to start using steel support materials due to the developments in the metallurgy, the second half of 19th century was a time for significant leaping forward of the tunnelling industry to change into a modern industry. However, the most important development in understanding the ground reactions and realising the contemporary support strategies were because of the new supports of rock bolts and shotcrete entering in tunnelling industry in 20th century.

The entrance of the new materials in applications caused not only many of the important improvements in the rock bolt support history to come true, but also all the topics in the rock engineering. The main idea of contemporary support is use of rock mass to support itself, which could be supplied by using rock bolts and shotcrete, preventing to carry dead load of rock mass. In the 20th century, many of the ground conditions which were quite difficult to excavate and support have become possible application areas as a result of using new materials, support methods, machines and new systems in rock engineering.

Although steel materials have caused big advantages in rock support applications, it has some lacks which need to be improved by use of new materials. New engineering polymers have been started to use as support materials because of their chemical resistivity, light density, high load bearing capacity especially against the dynamic loads. Nowadays, high strength new engineering polymers and composites are being produced and derived. To have better solutions in support practices, new polymeric materials and their composites should be assessed in comparison with other engineering polymers, which may have even better effects on support performance.

The success in today's rock bolting applications is result of many developments in different scientific disciplines and technology. A better focusing on the history of tunnel supporting would be helpful for new developments and enlarging the frontiers of the rock engineering.

References

Andre, G.G., 1876. A practical treatise on coal mining. E. and F.N. Spon, London.

Aspdin, J., 1824. An Improvement in the Modes of Producing an Artificial Stone. London: Patent number BP 5022.

Atlas Copco, 2015: http://www.atlascopco.ch

Baugh, G.C., Elrington, C.R., 1985. A history of the country of shropshire. Victoria country history, 11, 21-23.

BASF, 2009. Solutions for tunnelling and mining injections (Broschure of injection products), Zurich.

Bicik, M., 2012. Dünyada ilkler. Tutku, Ankara.

Bullock, R.L., 1974. Industry-wide trend toward all-hydraulically powered rock drill. Mining Congress Journal, 60, 54-65.

Davis, R.L., 1979. Split-set Rock Bolt Analysis. Int J Rock Mech Min Sci & Geomech Abstr, 16, 1-10.

Eckel, E.C., 1913. Portland cement materials and industry in the United States. Government Printing Office, Washington.

Firep, 2013: http://en.firepworld.com/company/profile

Gardlund, T., Janelid, I., Ramstrom, D., Lindblad, H., 1974. Atlas Copco 1873-1973. Atlas Copco AB, Stockholm.

Gardner, F.J., 1971. History of rock bolting, Symposium on Rock Bolting, The Australasian Institute of Mining and Metallurgy, Illawarra Branch, Paper No. 2, 11.

Hassell, R., Villaescusa, E,. 2005. Overcoring Techniques to Assess in Situ Corrosion of Galvanised Friction Bolts, Proceedings of 24th International Conference on Ground Control in Mining. Morgantown, WV, USA, pp 349-356.

Hoek, E., 2006. Kaya Mühendisliği (Turkish translation of "Rock Engineering"). Publication of The Chambers of Mining Engineers of Turkey, Ankara.

Holter, K.G., 2014. Loads on sprayed waterproof tunnel linings in jointed hard rock: A study based on Norwegian cases. Rock Mechanics and Rock Engineering, 47, 1003-1020.

Hutchinson, D.J., 1996. Diederichs MS. Cablebolting in underground mines. Bitech, Vancouver.

Hyett, A.J., Bawden, W.F., Coulson, A.L., 1992. Physical and mechanical properties of normal Portland cement pertaining to fully grouted cable bolts, In: Rock support in mining and underground construction. Balkema, Rotterdam, pp 341-348.

Jager, A.J., 1992. Two new support units for the control of rockburst damage, In: Proc. Int. Symp. on Rock Support in Mining and Underground Construction. A.A. Balkema, Rotterdam, pp 621-631.

Kaiser, P.K., Yazici, S., Nosé, J., 1992. Effect of stress change on the bond strength of fully grouted cables. Int J Rock Mech Min Sci Geomech Abstr, 29, 293-306.

Kovari, K., 2003a. History of the sprayed concrete lining method-part I: milestones up to the 1960s. Tunnelling and Underground Space Technology, 18, 57-69.

Kovari, K., 2003b. History of the sprayed concrete lining method-part II: milestones up to the 1960s. Tunnelling and Underground Space Technology, 18, 71-83.

Komurlu, E., 2012. Effects of rock and granular material horizontal stresses on support design. Karadeniz Technical University Mining Engineering Department, Trabzon, MSc thesis.

Komurlu, E., Kesimal, A., 2012. Using sprayed polymer as tunnel support, In: Proc. 7th Asian Rock Mechanics Symposium (ARMS 7), Seoul, South Korea, pp 1486-1499.

Komurlu, E., Kesimal, A., 2012. Poliüretan malzeme ile güçlendirilmiş zemin dayanımının incelenmesi, 14. ulusal zemin mekaniği ve temel mühendisliği kongresi bildiriler kitabı, Isparta, 631-642.

Komurlu, E., Kesimal, A., 2013a. New Support Materials for Forepoling and Umbrella Applications, In: Proceedings of 3rd International Symposium on Underground Excavations for Transportation, Istanbul, Turkey, 423-435.

Komurlu, E., Kesimal, A., 2013b. Tunnelling and Support Materials from Past to Present. The Journal of the Chamber of Mining Engineers of Turkey, 52, 33-47.

Komurlu, E., Kesimal, A., 2014. Improved Performance of Rock Bolts using Sprayed Polyurea Coating. Rock Mechanics and Rock Engineering, 48, 2179-2182.

Komurlu, E., Kesimal, A., Colak, U., 2014. Polyurea type Thin Spray-on Liner Coating to Prevent Rock Bolt Corrosion, 8th Asian Rock Mechanics Symposium, Sapporo, Japan, pp 1389-1397.

Komurlu, E., Kesimal, A., 2015. The usability of frictional rock bolts with plastic body. The Journal of the Chamber of Mining Engineers of Turkey (Accepted in November 2015).

Li, C., Lindblad, K., 1999. Corrosivity classification of the underground environment, In: Rock Support and Reinforcement Practice in Mining (Ed. by Villaescusa, Windsor and Thompson). Rotterdam, AA Balkema, pp 69-76.

Li, C.C., Stjern, G., Myrvang, A., 2014. A review on the performance of conventional and energy-absorbing rockbolts. Journal of Rock Mechanics and Geotechnical Engineering, 6, 315-327.

Meacham, S., 2007. Nifty idea made a whole lot of difference. The Sydney Morning Herald, June 4.

Muynck, W.D., Belie, N.D., Verstraete, W., 2009. Effectiveness of admixtures, surface treatments and antimicrobial compounds against biogenic sulfuric acid corrosion of concrete. Cement and Concrete Composites, 31, 163-170.

Muller, L., 1990. Removing the misconceptions on the New Austrian Tunnelling Method. Tunnels & Tunnelling, 22, 15-18.

Nelson, E.T., 1986. Automated temporary roof support system for mining equipment. United States Patent, Patent Number: 4595316

Ozturk, H., 2012a. Püskürtülen İnce Kaplamaların Elastik Özellikleri. Madencilik, 50, 41-45.

Ozturk, H., Tannant, D.D., 2010. Thin spray-on liner adhesive strength test method and effect of liner thickness on adhesion. International Journal of Rock Mechanics and Mining Science, 47, 808-815.

Parry, D., 2013. Engineering ancient world. The History Press, Glouchestershire.

Perez, H.T., 1952. Tunneling costs drop way down when bolts hold up tunnel roof. Constr Methods Equipment, March: 48.

Rabcewicz, L., Golser, J., 1973. Principles of dimensioning the supporting system for the "New Austrian Tunnelling Method". Water Power, March, 88-93.

Ranasooriya, J., Richardson, G.W., Yap, L.C., 1995. Corrosion Behaviour of Friction Rock Stabilisers Used in Underground Mines in Western Australia, 6th AusIMM Underground Operators Conference. Kalgoorlie, Australia, pp 9-16.

Sandstrom, G.E., 1963. The history of tunnelling. Barrie and Rockliti, London.

Scott, J.J., 1974. Friction rock stabilizers and their application to ground control problems. AIME-SME Fall Meeting.

Scott, J.J., 1981. Ground control technology transfer problems in metal and coal mines of the USA, 22nd U.S. Symposium on Rock Mechanics, pp 518-523.

Stauffer, D.M., 1906. Modern tunnel practice. Archibald Constable and Co Ltd, London.

Stephan, A., Frohlich, A., Klupfel, A., 1918. Verfahren zum abfangen und sichern des hangenden und der stosse im bergbau ohne stutzung von unten. Patentschrift Nr. 302909, Klasse 5c. Gruppe 4, Pat 25. Juli 1913y Ausgegeben 7. Januar 1918, Kaiserliches Patentamt Berlin.

Tannant, D.D., 2001. Thin Spray-on Liners for Underground Rock Support, 17th International Mining Congress and Exhibition of Turkey (IMCET 2001), pp 57-73.

Tully, D.M., 1987. Rock bolt reinforcement systems for coal mine roadways. University of Newcastle upon Tyne, PhD Thesis.

URL1: www.alibaba.com (June 2015)

Wahlstorm, E., 1973. Tunneling in Rock. Elsevier, Amsterdam.

West, G., 1988. Innovation and the rise of the tunnelling industry. Cambridge University Press, Cambridge.

Windsor, C.R., 1992. Cable bolting for underground and surface excavations, In: Rock support in mining and underground construction, Int. symp. on rock support. Balkema, Rotterdam, pp 349-376.

Yazici, S., Kaiser, P.K., 1992. Bond strength of grouted cable bolts. Int J. Rock Mech. Min. Sci. & Geomech. Abstr, 29, 279-292